Managing Technology Development: Insights from the Mini AERCam R&D Project

Project Management Challenge 2006

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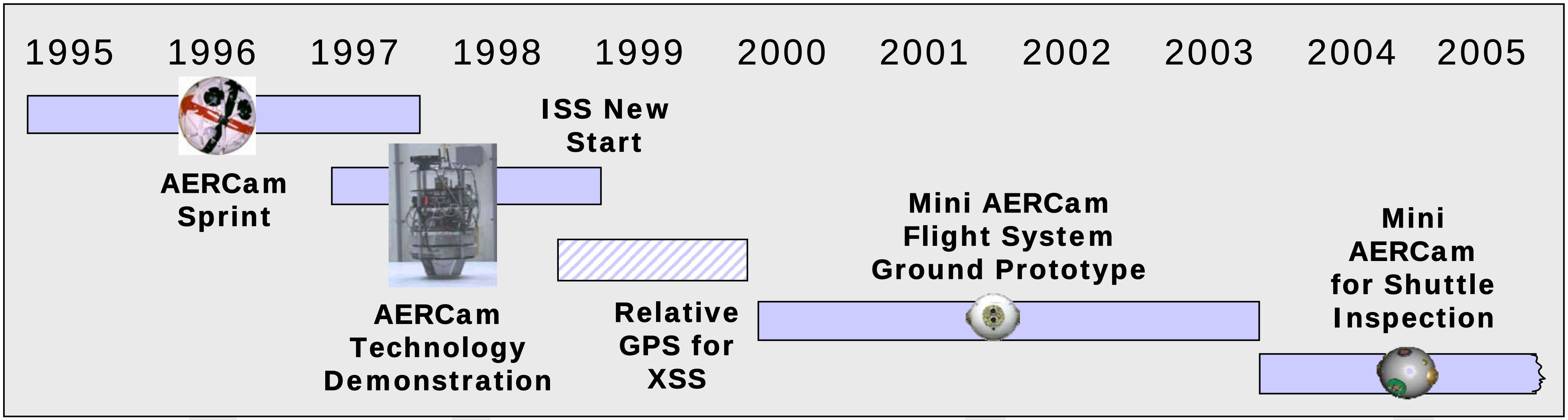
Presentation Outline

- **About the Project: AERCam Background**
  - History
  - Mini AERCam project overview

- **Project Management Insights**
  - Project Management Processes
  - Lessons Learned

AERCam History

Over 10 years of development history at JSC



Flight test of protoflight unit on STS-87 in 1997

Testbed for advanced autonomous technologies

Ground demonstration of flight-like integrated design

Flight system development for Shuttle Inspection

AERCam Sprint

Over 10 years of development history at JSC

1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005

AERCam Sprint

ISS New Start

AERCam Technology Demonstration

Relative GPS for XSS

Mini AERCam Flight System Ground Prototype

Mini AERCam for Shuttle Inspection

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AERCam Sprint on STS-87

- Free flying camera
- Flight tested in December 1997 on STS-87
- Released during EVA by Winston Scott
- Remotely piloted by Steve Lindsey from the Orbiter aft cockpit
- Flown for over an hour around the Payload Bay
- Sprint provided color video
- 14-inch diameter, 35 pounds
- Demonstrated capabilities included automatic attitude hold, manual maneuvers

AERCam Sprint Flight Video

Path to Operational Capability

Sprint proved stable video of external points of interest can be obtained using a teleoperated free flyer.

Following Sprint, the JSC Engineering Directorate embarked on an effort to provide increased capabilities for a free flying inspection system, while maturing the needed technologies and validating requirements through crew participation.

- Follow on development project resulted in an integrated demonstration of new free flyer technologies for free flyer autonomy and operator situational awareness
  - Differential carrier phase GPS navigation
  - Autonomous maneuvering
  - Visual guidance
  - Obstacle avoidance

AERCam Technology Demonstration

Over 10 years of development history at JSC

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AERCam Sprint

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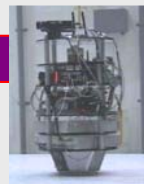

AERCam Technology Demonstration

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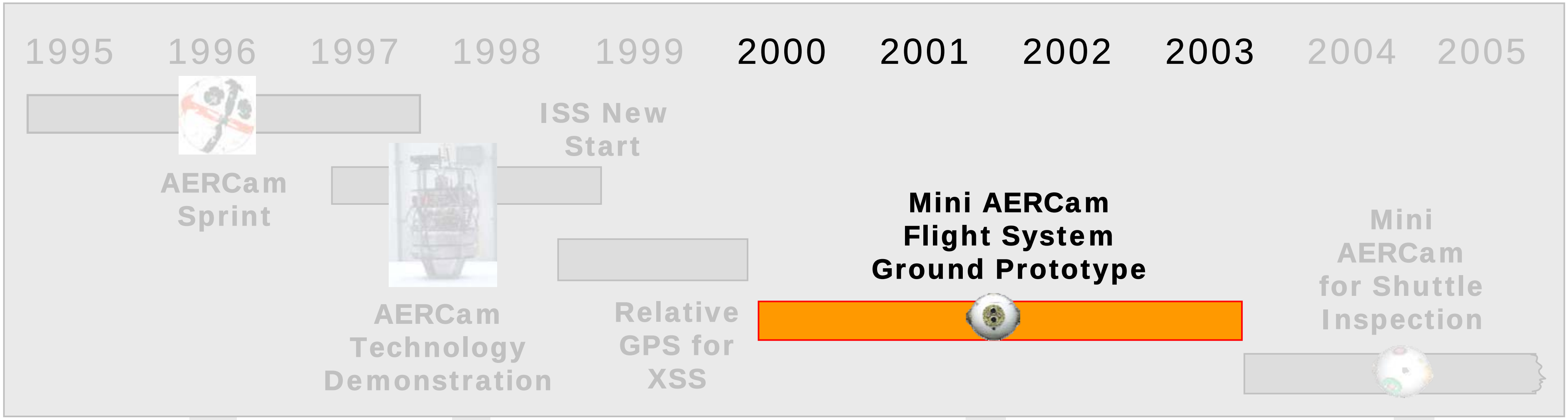

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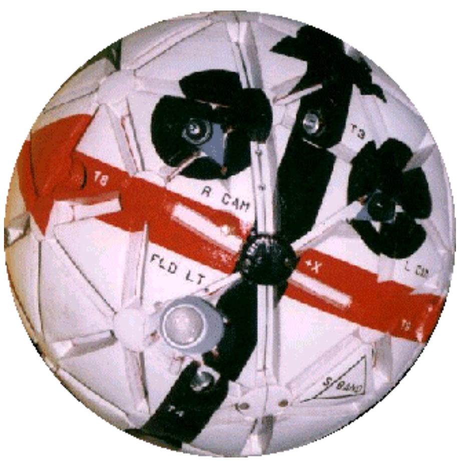
Free Flyer Capability Comparison

Sprint:

- 6-DOF manual control
- Automatic attitude hold
- Analog video

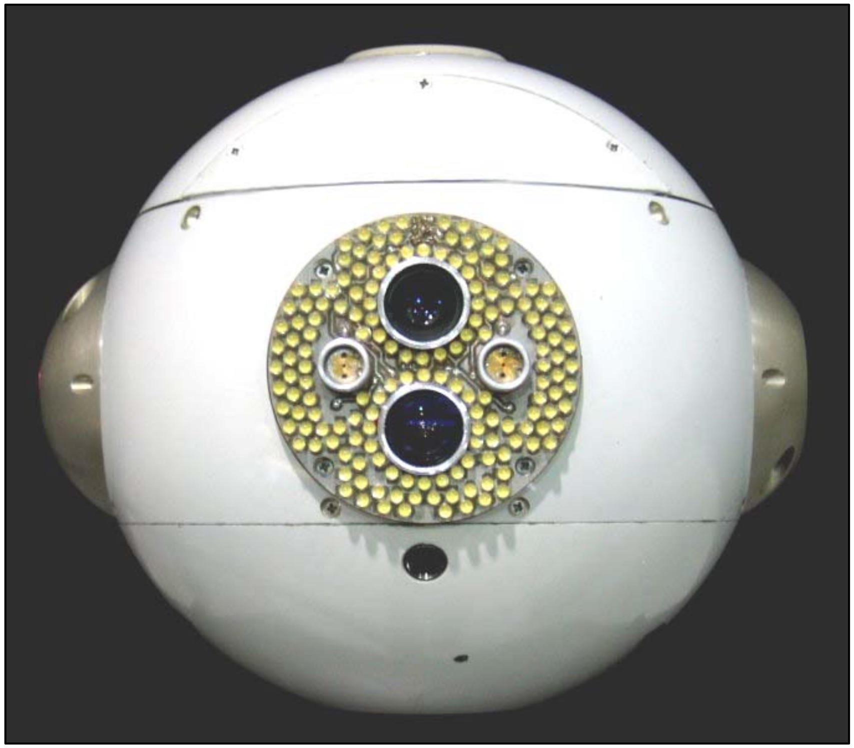


Mini AERCam:

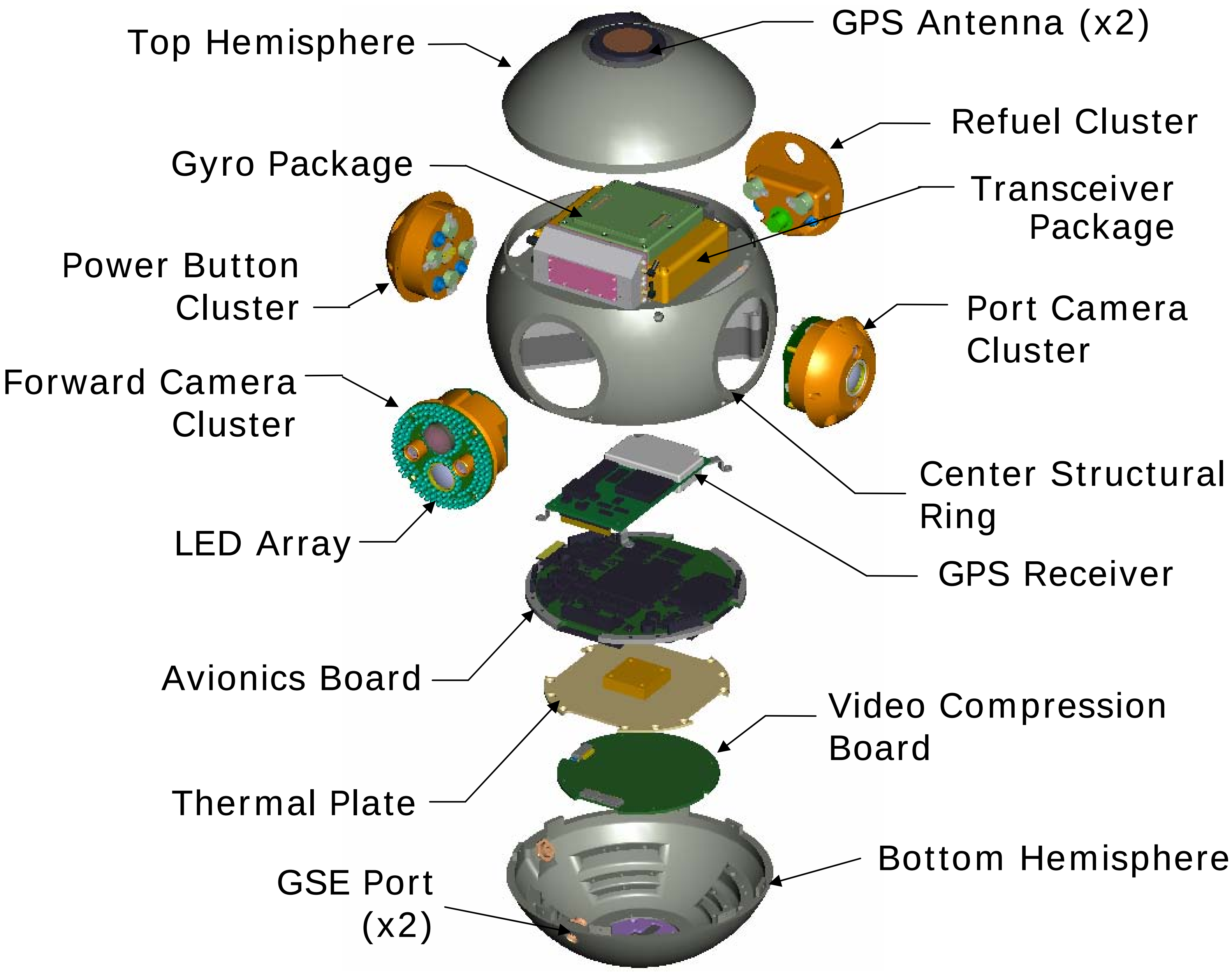
- 6-DOF manual control
- Automatic attitude hold
- Commanded attitude maneuvers
- Automatic position hold (relative)
- Commanded translation maneuvers
- Automatic surface scans
- Situational awareness (God's Eye View)
- Digital video
- Automatic docking
- Rechargeable battery
- Rechargeable propulsion

Mini AERCam Flight Prototype

- **Nanosatellite size (lower launch mass, lower power, safer)**
  - 7.5 inches in diameter, 10 lbs
- **Components are "one step from flight"**
- **Increased technology readiness across all subsystems**
- **Matured overall system technology readiness**



Mini AERCam Flight Prototype Components



Mini AERCam
Free Flyer Technologies (1 of 2)

PROPULSION

- **Rechargeable pressurized xenon gas propulsion**
  - 6 DOF thrusting capability (12 thruster configuration)
  - Compatible with nitrogen for ground operations

POWER

- **Rechargeable batteries (Li-Ion chemistry)**

VIDEO

- **CMOS color cameras (“Camera on a chip”)**

ILLUMINATION

- **Solid state illumination (LEDs)**

DOCKING

- **Electromagnetic docking**
- **AutoTRAC Computer Vision System (ACVS) for docking navigation**

Mini AERCam
Free Flyer Technologies (2 of 2)

AVIONICS

- PowerPC 740/750 based design
- FPGA-centric architecture

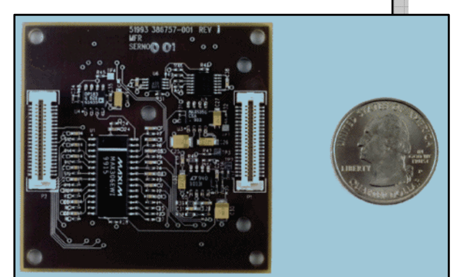
Avionics Processor Board

COMMUNICATIONS

- Digital transceiver for video, commands, and telemetry
- Micro-patch antennas for communications and GPS navigation

GN&C

- MEMS angular rate gyros for propagated relative attitude

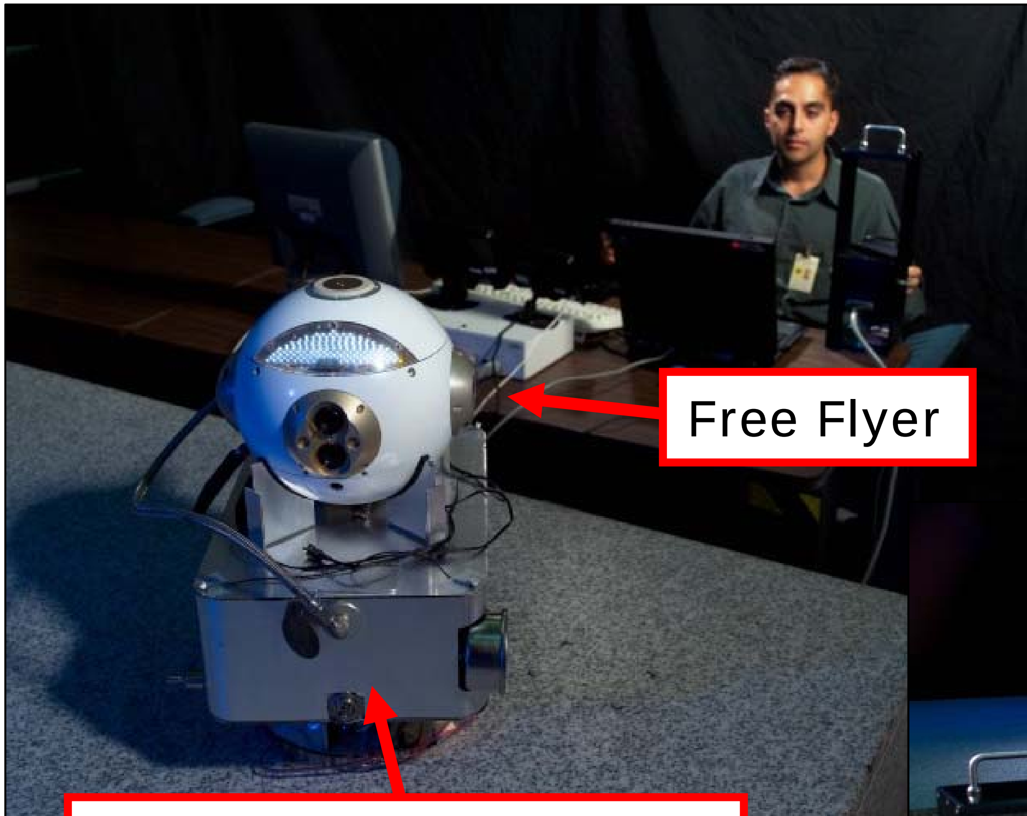


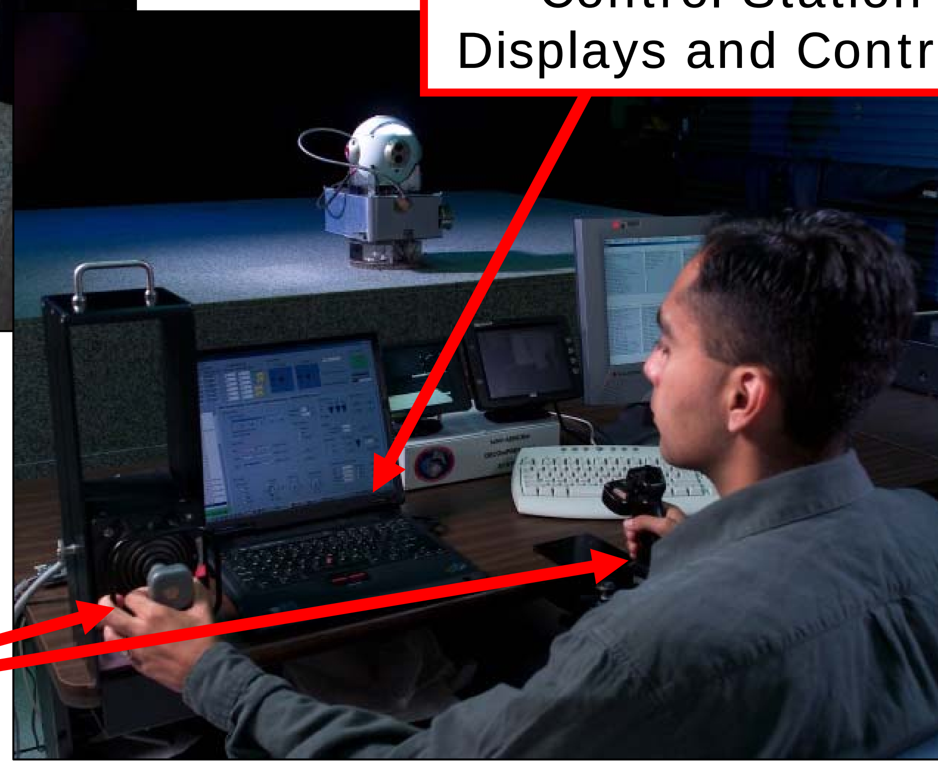
MEMS Rate Gyros

- Relative navigation via GPS mini-receiver
- Pilot aids: Automatic attitude hold, LVLH hold, attitude maneuvers, translation hold, point-to-point guidance

Air Bearing Table Test Facility

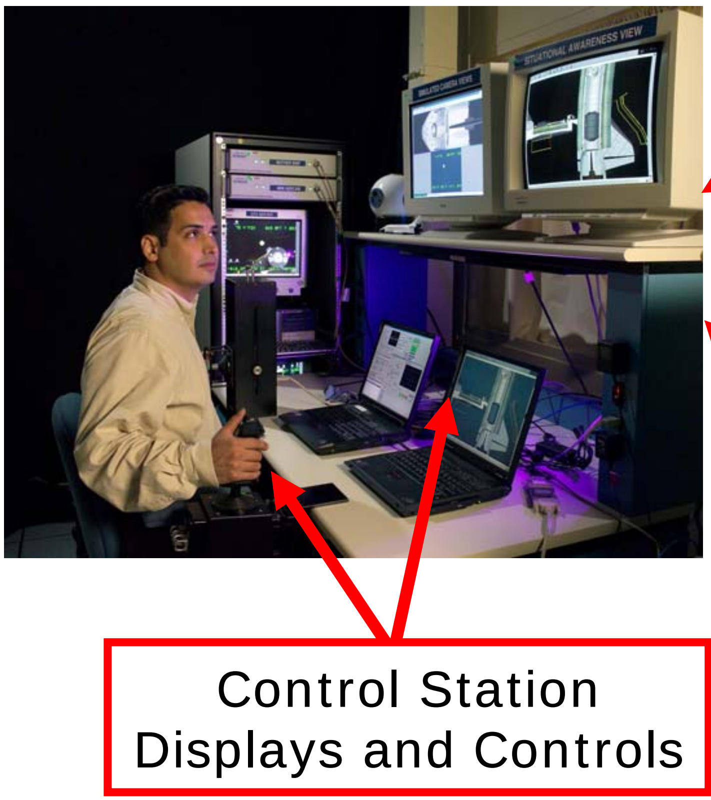
- Provides software and hardware testing on frictionless surface for testing in 3 degrees of freedom
- Incorporates avionics, flight software, video, MEMS gyros, communications, batteries, and propulsion.

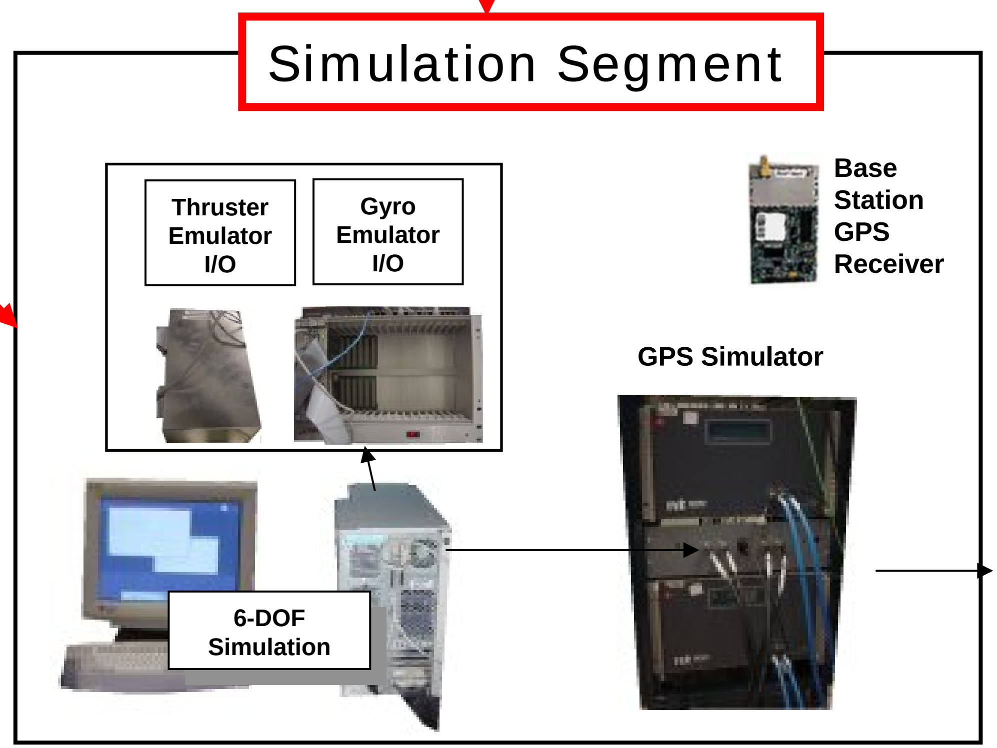




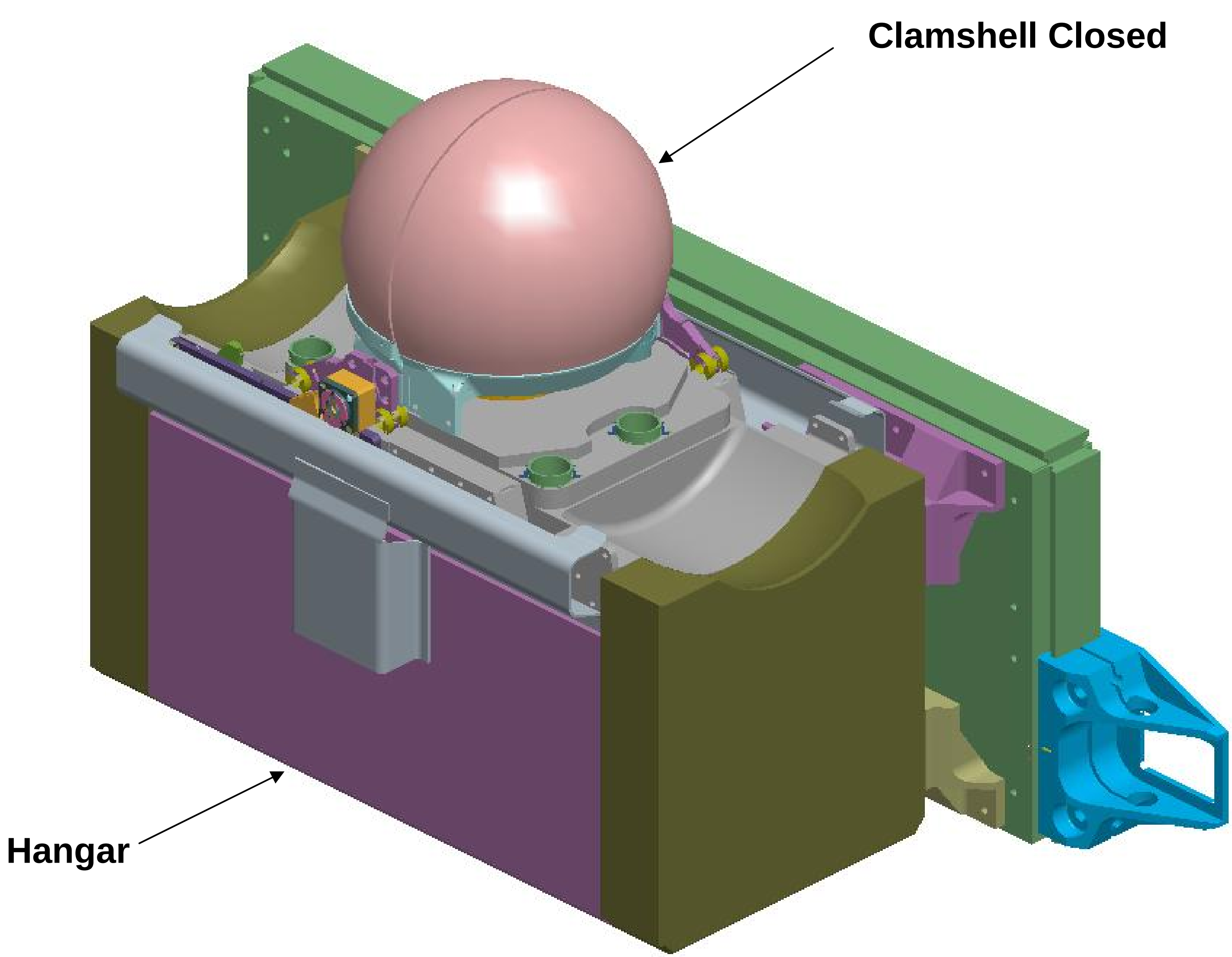
Orbital Simulation Test Facility

- Software and avionics testing in space-like environment.
- Hardware in the loop test facility, including avionics, flight software, communications, and GPS.





Hangar Concept (Closed Configuration)



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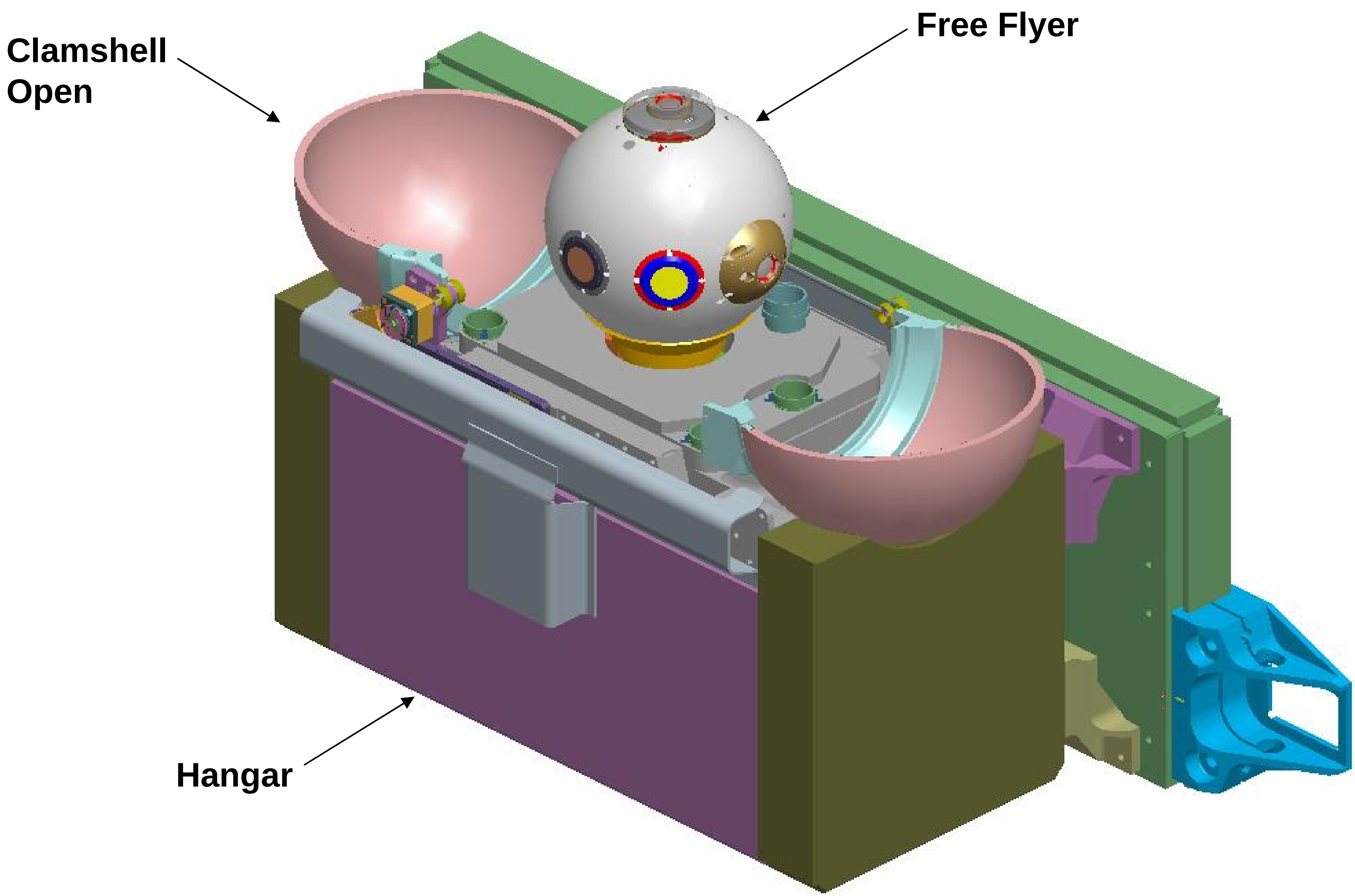
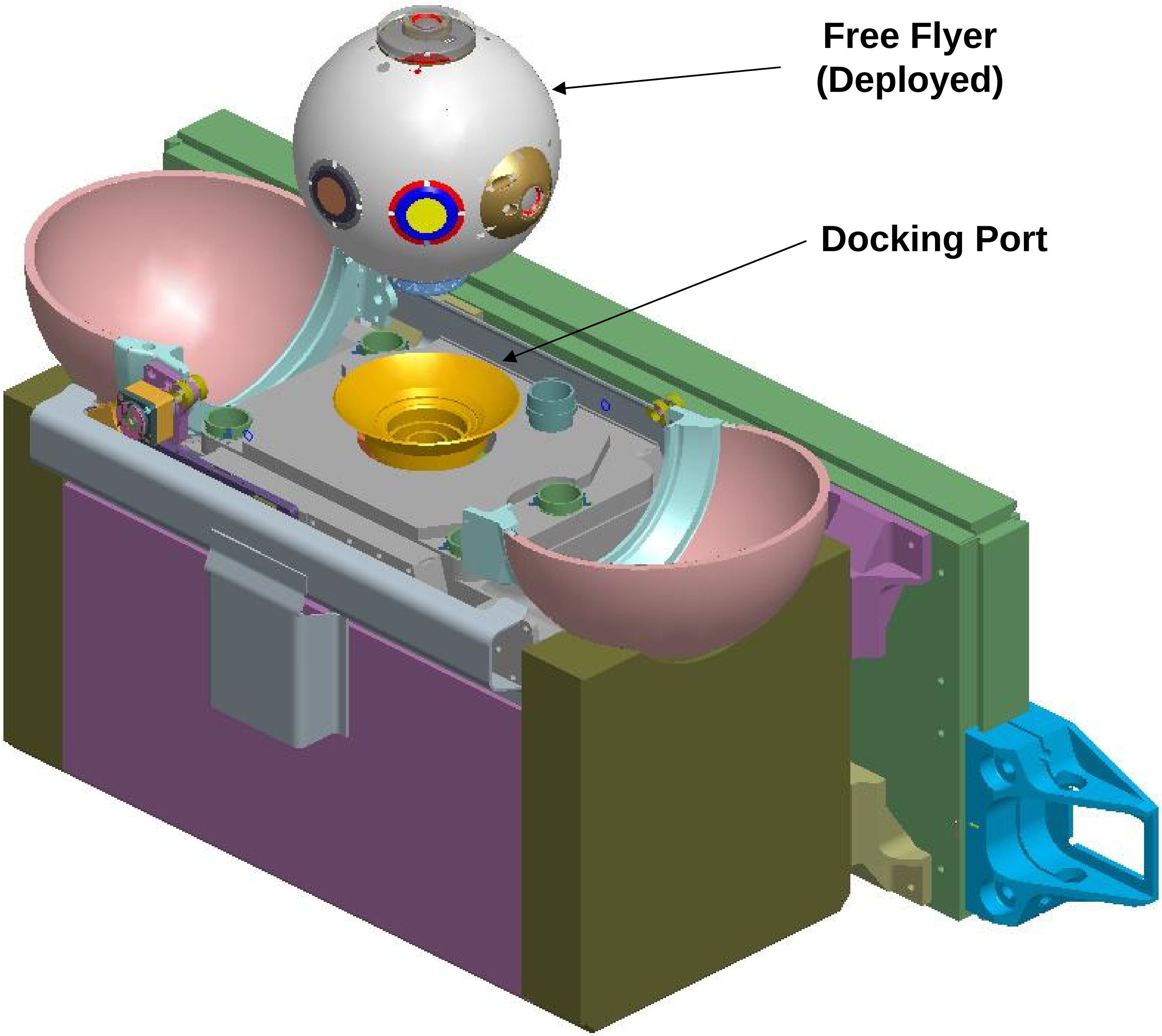
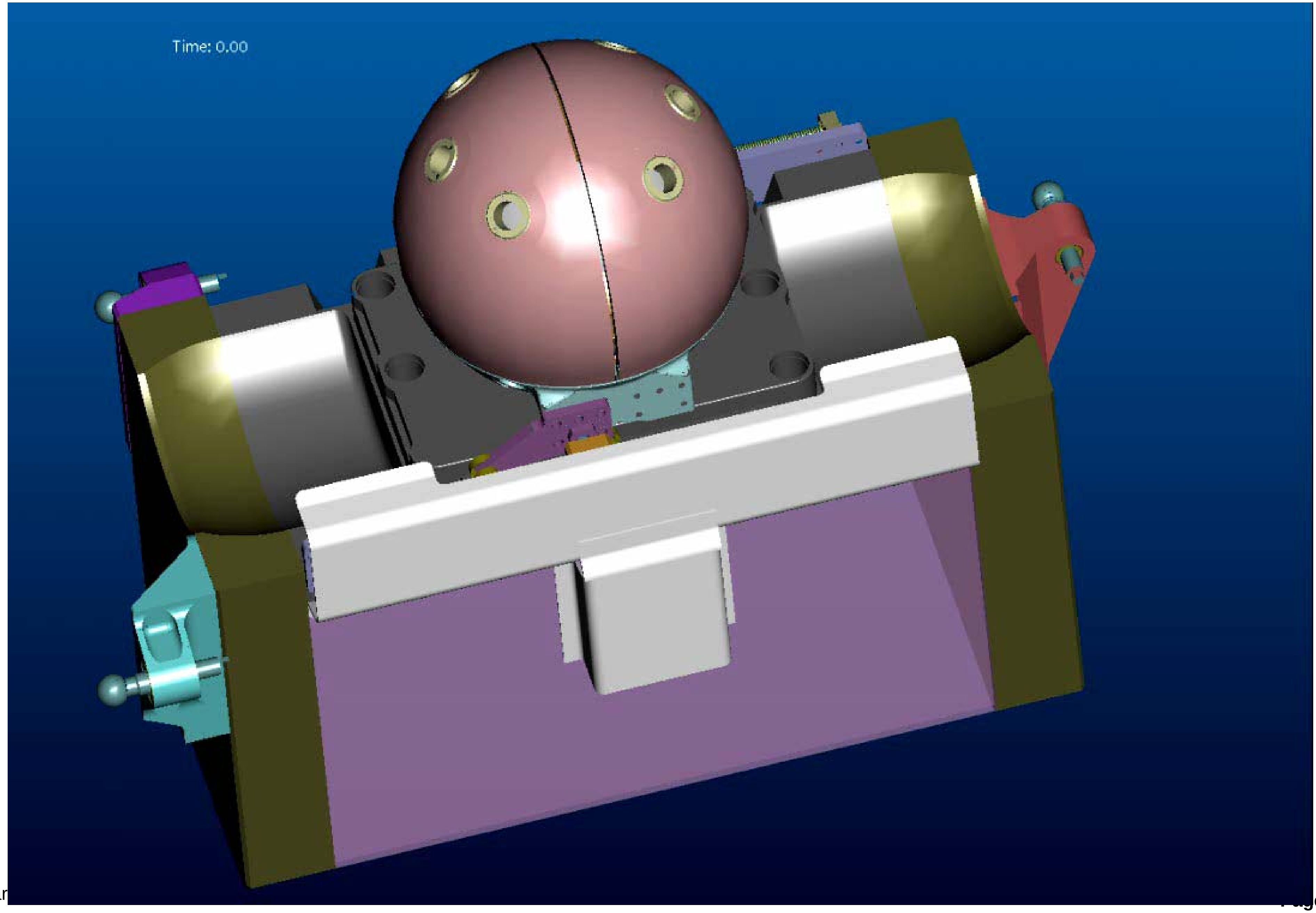


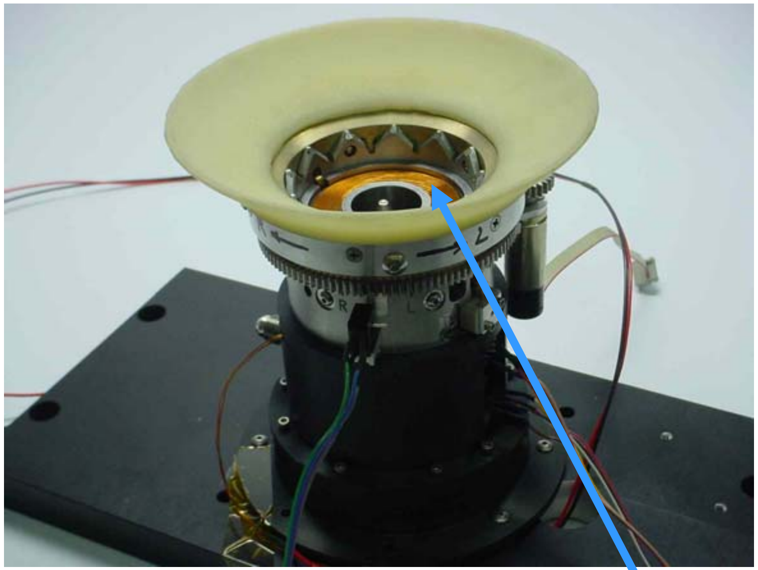
Free Flyer Deployment from Hangar

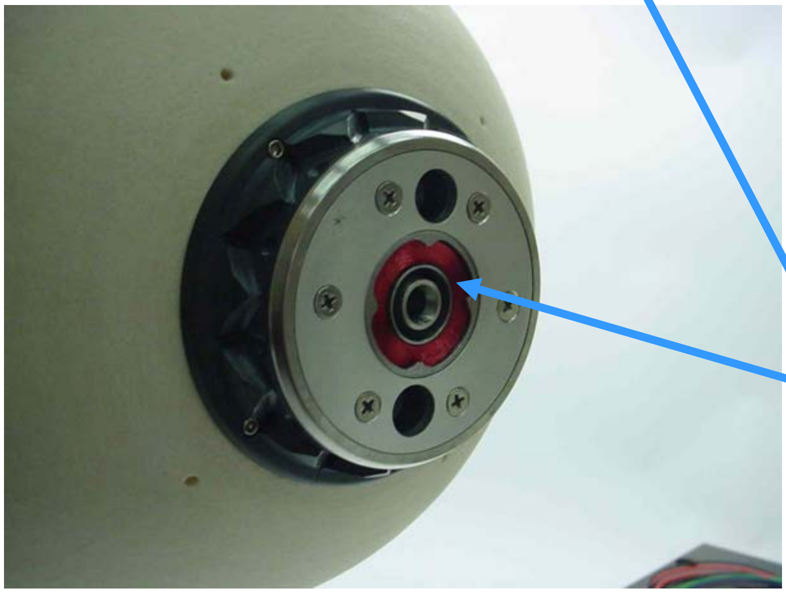


Hangar Animation



Magnetic Docking Mechanism



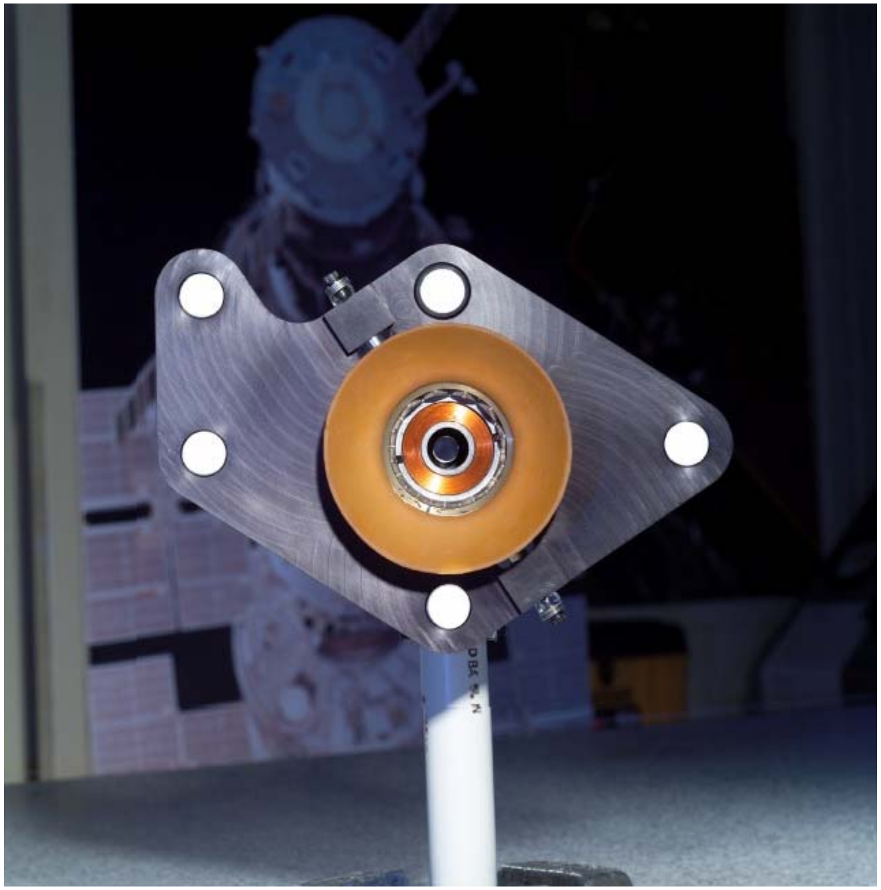


Docking Prototype Hardware on Air Bearing Table

Electromagnets on Free Flyer and Hangar

Closed-Loop Docking Airbearing Testing

Mini AERCam Free Flyer
on Airbearing Table

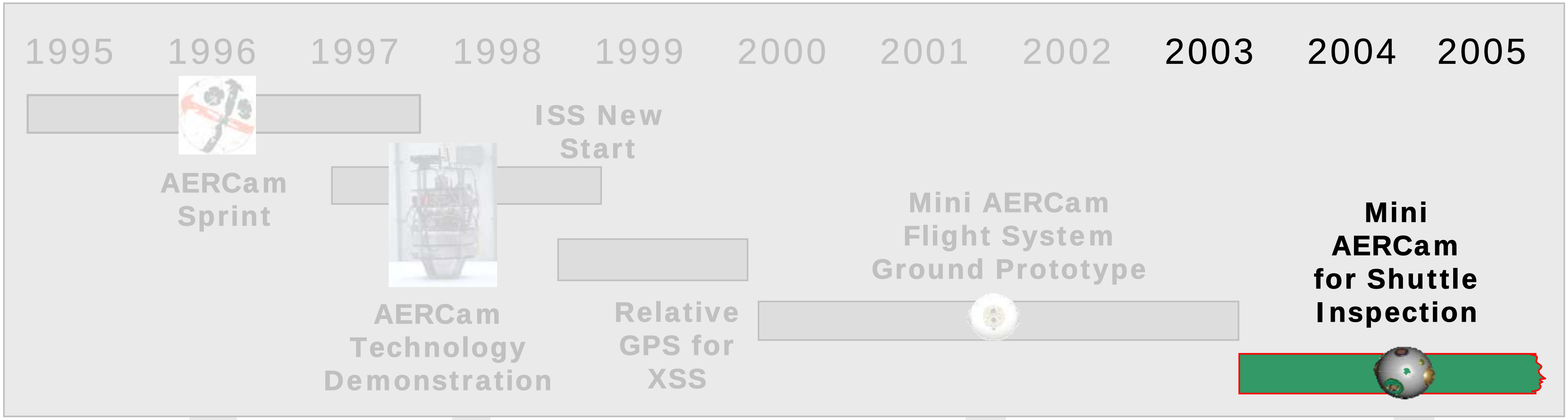


Docking port and ACVS
Docking Target

Mini AERCam Docking on Air Bearing Table

Mini AERCam for Shuttle Inspection

Over 10 years of development history at JSC



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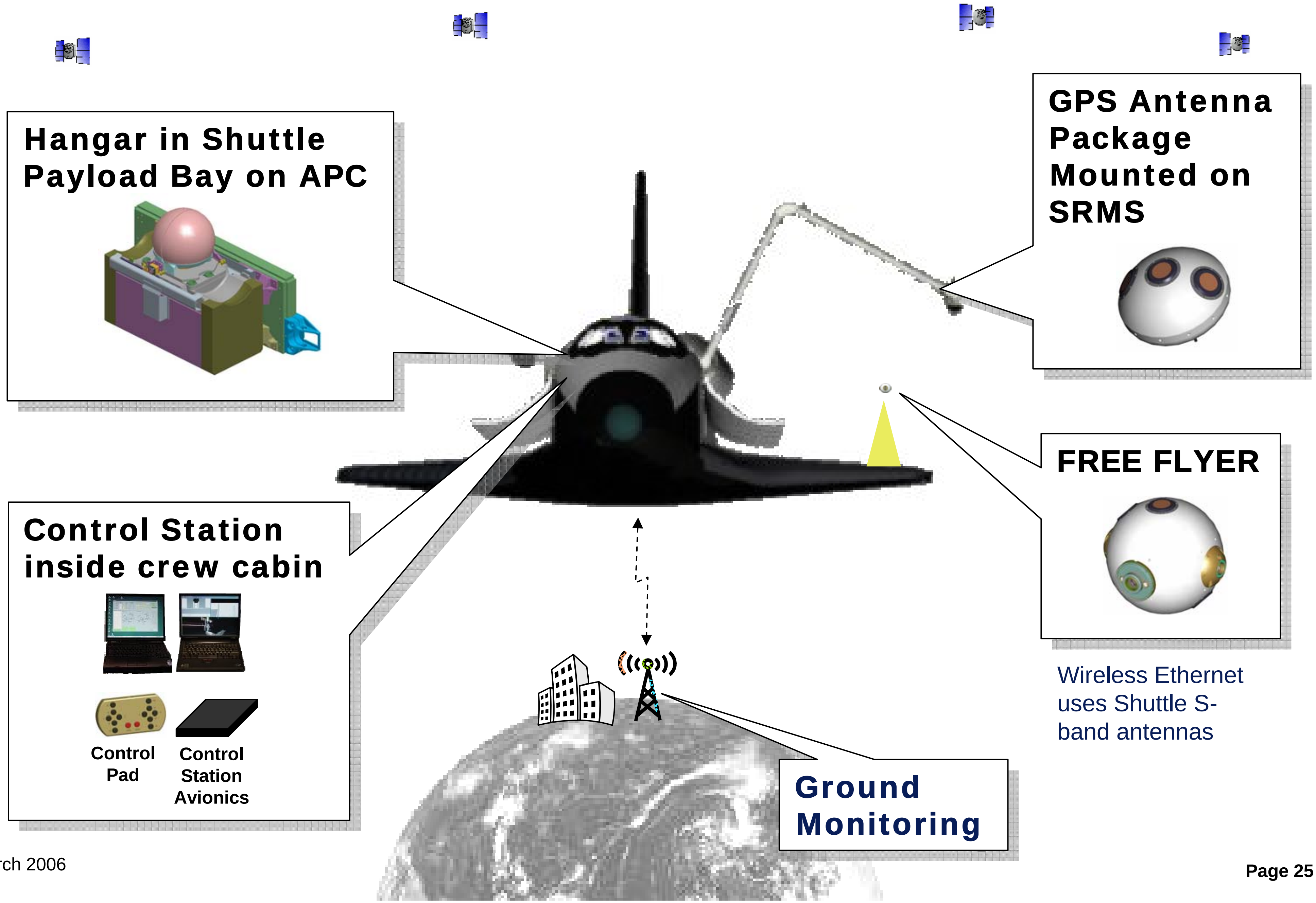
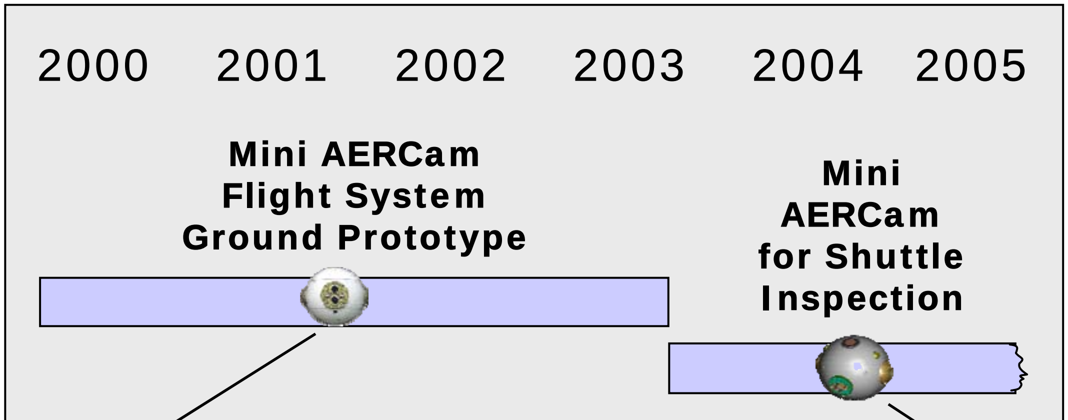


Mini AERCam Project Management Insights
and
Lessons Learned

Project Environment



- **Core Mini AERCam technology demonstration project executed from 2000 to 2002**
  - Free flyer and control station development
  - Primarily NASA civil servant team (on-site JSC)
  - Internal sponsor/customer

- **Additional technology development from 2003-2005 conducted during migration to flight-oriented activities**
  - Docking system design developed during flight system formulation
  - Core development team substantially unchanged
  - Multiple sponsorship changes
  - Migration to flight development processes for get-ahead work during proposal development

Project Management Processes

- **Separate formulation phase prior to project initiation**
  - Intense ~4 week project formulation and feasibility assessment in February 2000
  - Small team within JSC Engineering Directorate
  - Formulation direction:
    - » Embrace/develop advanced subsystem technology for miniaturization (“high tech”)
    - » One step from flight (no technology gaps)
    - » Integrate 8 inch free flyer and demonstrate
  - Feasibility results presented in March 2000 leading to project approval
  - After project initiation, the formulation team became the core members of the development team

Project Management Processes (continued)

- **SE&I**
  - 3 loci of subsystem integration and configuration control
    - » Mechanical (packaging/volume, & mass)
    - » Avionics (power and data interfaces)
    - » Software (hardware/software integration)
- **Lean processes**
  - Weekly team meetings with Action Items
  - RAZOR and ClearCase for issue tracking
    - » Also software configuration control
  - Infrequent project-level reviews
  - Other “forcing functions” for system Q/A
    - » Demonstrations to senior managers
    - » Astronaut crew evaluation
    - » Peer reviews

What Worked: Requirements Management

- **Requirements stability: Uncompromising approach to allocations for volume, mass, power, and functional requirements**
  - Top-level requirements remained highly stable after feasibility assessment phase
  - Innovation allowed to thrive within envelope
    - » Even Wireless Ethernet retrofit adhered to "original" requirements
  - Blatant depiction of mechanical interferences at team meetings to force correction
    - » PM goal of 7.5 inch diameter unchanged

What Worked: Design and Analysis

- **Assembly and servicing requirements considered in the design of free-flyer**
  - Semi-modular design provides dense packaging arrangement while facilitating servicing with minimal risk of collateral damage
- **Early emphasis on thermal design**
  - Sensitivity to local thermal challenges, not just power distribution
- **Other flight oriented analyses & testing (delta-V, communications, navigation, radiation) conducted during tech development**
  - Necessary to make system “one step from flight”
  - “Expected” project to proceed to flight

What Worked: Integration

- **Centralized avionics facilitated successful avionics integration**
  - Avionics processor board served as hub for data interchange and power distribution
  - FPGA-centric avionics processing provided flexibility in critical asset
- **Software common data area (CDA) facilitated integration and expandability**
- **Hardware software integration "queue" effective during development phase**
  - 2-3 days avionics processor board time per subsystem then back to end of the queue

What Worked: Testing

- **Airbearing table and orbital simulation provided a good combination for tests and demonstrations**
  - High fidelity simulation saved effort in long run compared to a software-only simulation
  - Used both to isolate facility issues from free flyer issues

What Worked: Team Dynamics

- **Moderate team turnover**
  - Large fraction of feasibility assessment team remained on project team for duration
  - Enabled lean processes and documentation
- **Co-located software developers**
  - Improved communications but did not by itself ensure optimum interaction
- **Concurrent engineering: Manufacturing lead on design team**
  - Worked with mechanical designers directly and reduced bureaucracy
  - Almost no rework of mechanical parts (only 2 items total)

Harder Lessons

- **Wireless communications development issues**
  - Late and limited involvement during feasibility assessment/formulation phase lead to early technology “retreat”
  - Over-reliance on remote contractor specialist for first fall-back technology
  - Project failure to respond immediately at first signs of trouble
  - Recovery:
    - » Retrofitted wireless Ethernet extremely late in the project
    - » Use wired “serial Ethernet” for non-dynamic testing until retrofit complete
  - Lesson for future: More risk sensitivity analysis during feasibility phase

Harder Lessons (continued)

- **Free flyer wiring issues**
  - Late emphasis on harness design threatened mechanical baseline
    - » E.g. interference with adjacent structure due to bending radius constraints
  - No effective alternative to long-lead single-source components
    - » Vendor performance jeopardized schedule
  - Recovery: Dealt with mess of spliced cables while waiting for final harnesses
  - Lesson for future: Worry about all the “small stuff” early if it affects integration

Technical Observations

- **Initial selection of a sphere instead of cube**
  - Spheres appear smaller than equivalent volume cubes
  - Cubes with rounded corners approach spherical form
  - We preferred a sphere anyway – for safety and other reasons
- **Given spherical free flyer, use circular boards, circular thruster clusters, and circular antennas**
  - **“**Cutting square holes in spherical surfaces does not work well”
- **CMOS imagers**
  - Numerous peculiarities, sometimes poorly documented
- **MEMS gyros**
  - Tremendous potential but still developmental technology

Migration to Flight

- **Scope change**
  - Conducted flight system enabling design & analysis to ensure technology was aligned with anticipated Shuttle needs
  - Selected parts for flight design
  - Continued development of autonomous docking and recharge capability
- **Process change**
  - Modified team organizational structure
  - Added weekly internal technical interchange (TIM) and SE&I meetings
    - Alternating “status” and special topic TIMs
  - Multilayered schedule with linked milestones
    - Strong for integration phase (like technology phase) but weaker for early dependencies
  - Additional tools selected
    - DOORS for requirements (replacing Word/Excel)
    - ARM for risk management (replacing Excel)

Other Project Management Thoughts

- Don’t assume co-location guarantees communication
- Hold a weekly meeting to force communication
- Beware “2 week” estimates for software tasks
- Lean process approach works best with low turnover team